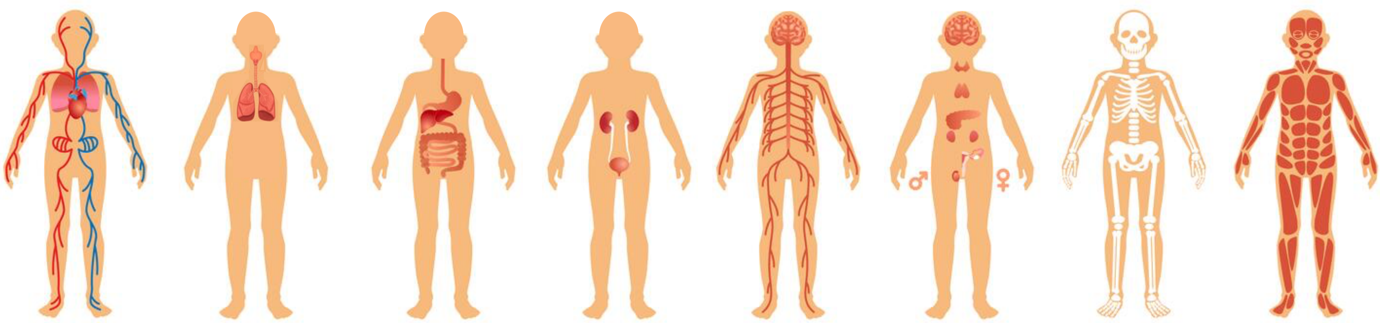
SYSTEM INTEGRATION

Content Statements:

C3.1.1	System integration
C3.1.2	Cells, tissues, organs and body systems as a hierarchy of subsystems that are integrated in a multicellular living organism
C3.1.3	Integration of organs in animal bodies by hormonal and nervous signalling and by transport of materials and energy
C3.1.4	The brain as a central information integration organ
C3.1.5	The spinal cord as an integrating centre for unconscious processes
C3.1.6	Input to the spinal cord and cerebral hemispheres through sensory neurons
C3.1.7	Output from the cerebral hemispheres to muscles through motor neurons
C3.1.8	Nerves as bundles of nerve fibres of both sensory and motor neurons
C3.1.9	Pain reflex arcs as an example of involuntary responses with skeletal muscle as the effector
C3.1.10	Role of the cerebellum in coordinating skeletal muscle contraction and balance
C3.1.13	Control of the endocrine system by the hypothalamus and pituitary gland

BODY SYSTEMS

In multicellular organisms, each individual cell needs to communicate with other cells in order to maintain organismal survival. Cells group together to form **tissues**; different tissues interact to form **organs** and organs are integrated into **body systems**. The collective actions of these different structures combine to create new synergistic effects – known as **emergent properties**. For example, individual cells are incapable of conscious behaviours but millions of interacting nerve cells enable the capacity for critical thought and decision making. Animals contain a myriad of body systems that function to promote growth and survival:



Vascular | Respiratory | Digestive | Excretory | Nervous | Endocrine | Skeletal | Muscular

COMMUNICATION NETWORKS

In order for multicellular organisms to function, there must be a mechanism for communication between the different body systems. Animals contain two means by which individual cells can become integrated:

- **Nervous system:** A rapid communication system involving the conduction of electrochemical impulses
- **Endocrine system:** A widely distributed network that uses chemical messengers for prolonged effects

Additionally, specific materials and energy can be transferred between cells via the blood (vascular) system.

NERVES VS HORMONES

The nervous and endocrine systems differ in a number of key aspects which influence and inform the roles that they perform in multicellular communication. Some of the differences between the systems include:

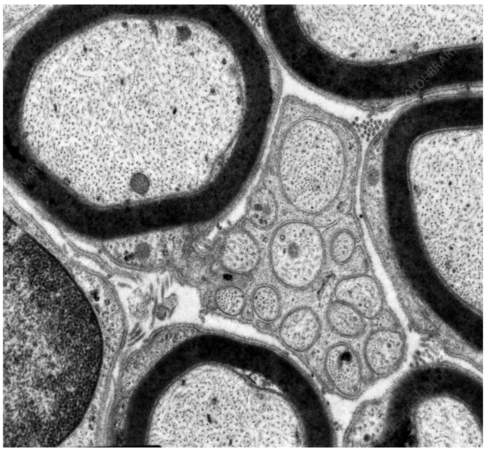
	Nervous System	Endocrine System
Type of Message	Electrical impulses travelling along connected nerve cells (neurons)	Chemical messengers (hormones) released into the bloodstream
Speed of Action	Very rapid signal transmission	Transmission of signal can be slow
Response Duration	Response is rapid and brief	Response may be sustained
Area of Effect	The effect is specific and localised	The effects may be widespread

NERVOUS SYSTEM

The nervous system coordinates the actions of complex organisms via the transmission of electrochemical signals. These signals are transmitted by a specialised network of cells called neurons. The nervous system can be divided into two key parts – the central nervous system (CNS) and peripheral nervous system (PNS).

The **central nervous system** is made up of the brain and spinal cord. It functions as a central information integration organ by processing information from a variety of inputs and coordinating necessary responses. The brain is an integrating centre for conscious processes and is responsible for a range of higher order cognitive functions – including learning, memory, emotion and critical thought. The spinal cord functions as a connection point between the brain and the peripheral nerves. It also acts as an integrating centre for certain unconscious processes that do not require the involvement of the brain (these are reflex actions).

The **peripheral nervous system** is made up of sensory and motor neurons that transmit information to or from the central nervous system. These neurons are organised into bundles of nerve fibres that collectively form a nerve. Each nerve enables communication with a specific region of the body. Afferent nerves send signals to the central nervous system (via sensory neurons), while efferent nerves function to send signals from the central nervous system (via motor neurons). Individual neurons may be wrapped within a layer of fatty tissue called the myelin sheath, which insulates the nerve cell and improves transmission speeds (i.e. faster signalling). However, myelinated fibres take up more space and have greater energy requirements, meaning not all nerve fibres are myelinated.



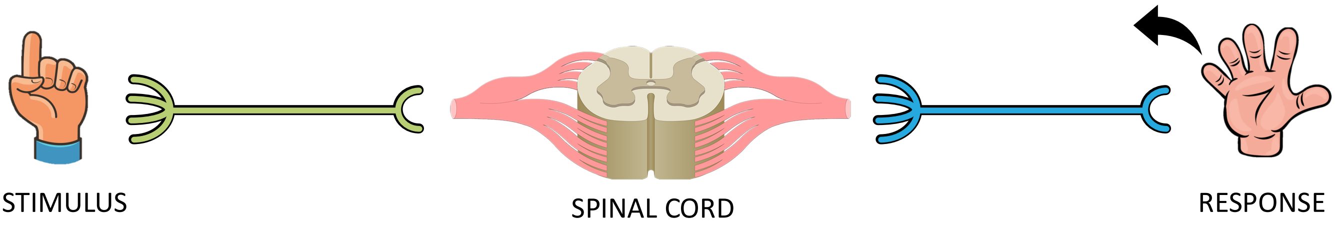
Myelinated and unmyelinated fibres

STIMULUS RESPONSE MODEL

The basic pathway for a nerve impulse is described by the stimulus-response model. A stimulus represents any change to the environment (external or internal) that is detected by a **receptor**. Receptors convert the stimulus into an electrical impulse that is transmitted via sensory neurons to the central nervous system, where processing of the signal occurs. When a response is determined (either conscious or unconscious), an impulse is transmitted via motor neurons to an **effector** organ – which is either a muscle or a gland. The effector then generates a response. Muscles are stimulated to contract and enable movement, while glands release chemicals (endocrine glands release into the bloodstream, exocrine glands release onto surfaces).

REFLEX ACTIONS

A reflex is a rapid and involuntary response to a stimulus, resulting from a simple signalling pathway called a **reflex arc**. Reflex actions do not involve the brain – instead sensory information is relayed directly to the motor neurons via the spinal cord. This results in a fast response that does not involve conscious thought or deliberation. Reflex actions are especially beneficial in survival situations, when quick reactions are needed to avoid permanent damage. An example of a reflex arc is a pain response pathway. The free nerve ending of a sensory neuron acts as a pain receptor and transmit a signal to a single interneuron within the grey matter of the spinal cord. The impulse is transmitted via a motor neuron to the local muscles, which then contract and move the impacted appendage away from the source of discomfort.



THE BRAIN

The brain functions as the main integration centre of the central nervous system. While the spinal cord can regulate certain unconscious processes (reflex actions), only the brain is capable of the coordination and integration of more complex actions – including learning, memory, emotions and consciousness. The brain is organised into three main structures – the cerebral hemispheres, the cerebellum and the brain stem.

Cerebral Hemispheres

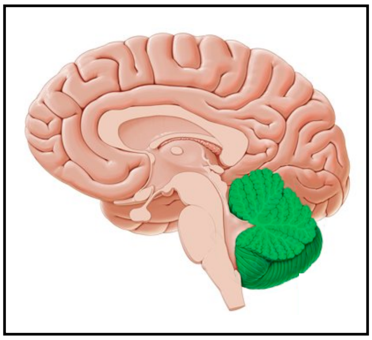
The cerebral hemispheres (collectively called the **cerebrum**) are responsible for the processing of most higher order functions. They are heavily folded (gyrification) to increase cognitive capacity and are divided into four topographical lobes that specialise in the integration and coordination of distinctive functions:

- **Frontal lobe** – Controls voluntary motor activities, speech production and tasks involving dopamine
- **Parietal lobe** – Responsible for sensory perceptions, such as touch sensation (tactility), smell and taste
- **Occipital lobe** – The visual processing centre of the brain (used for sight perception and interpretation)
- **Temporal lobe** – Involved in auditory processing (i.e. hearing) and the comprehension of language

Not all complex tasks are equally represented by both cerebral hemispheres – some activities are localised to a single side. For example, speech production is coordinated by Broca's area, which is situated in the *left* frontal lobe of the brain. Additionally, each hemisphere processes sensory and motor information for the opposite side of the body. Information can be passed between the two hemispheres by a bundle of myelinated nerve fibres embedded within the brain. These fibres form the **corpus callosum** to facilitate interhemispheric communication.

Cerebellum

The cerebellum is a separate structure located at the base of the brain. It is responsible for the coordination of complex motor actions – which includes balance and proprioception. The cerebellum coordinates gait, controls your posture and is involved in maintaining muscle tone. While the cerebellum helps to control voluntary muscle activity, it does not initiate contractions – that is controlled by the primary motor cortex in the frontal lobe. The term cerebellum is derived from Latin and essentially translates to 'little brain'.

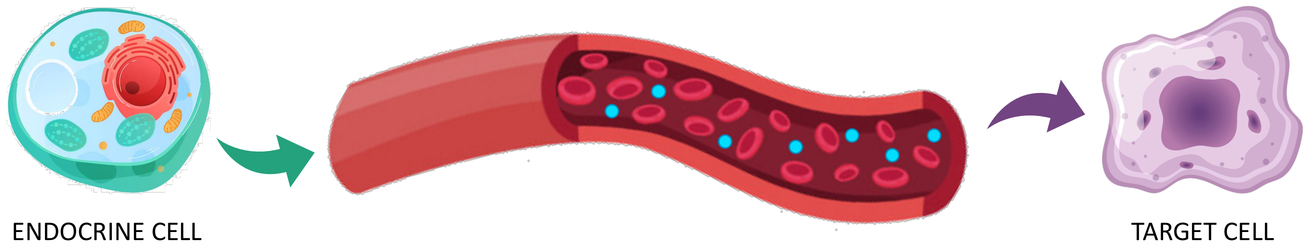


Brainstem

The brainstem is the structure that acts to connect the cerebrum to the spinal cord and the cerebellum. It consists of the midbrain, pons and medulla oblongata. The brainstem controls involuntary and unconscious functions – like breathing and heart rate. These actions do not require conscious intervention, which is why people in vegetative states may still be alive – as the brainstem maintains these critical survival functions.

ENDOCRINE SYSTEM

The endocrine system consists of a network of ductless glands that release chemical messengers that are called **hormones** directly into the bloodstream. This chemical release allows for a more widespread and longer lasting response. The hormones bind to specific receptors and only activate cells with the particular receptor. Hence, endocrine activity can be controlled by modifying either the amount of hormone released from the endocrine gland or the quantity of receptor expressed on the appropriate target cell. Hormones can either be hydrophilic proteins that bind to external receptors or hydrophobic lipids (i.e. steroids) that can freely cross the phospholipid bilayer and bind to receptors within the cytoplasm of the target cells.



HYPOTHALAMUS

The endocrine system is controlled by a region of the brain called the hypothalamus. The hypothalamus functions as a homeostatic control centre and regulates hormonal secretion via a 'master gland' called the **pituitary gland**. This gland lies adjacent to the hypothalamus and consists of anterior and posterior lobes. The hypothalamus produces releasing factors which trigger the release of hormones synthesised by the anterior lobe. Additionally, the hypothalamus also produces certain hormones itself, which are released from the posterior lobe. The hormones released from the pituitary gland may act directly on body tissues, but may also act to stimulate the activity of other endocrine glands (e.g. TSH stimulates the thyroid gland).

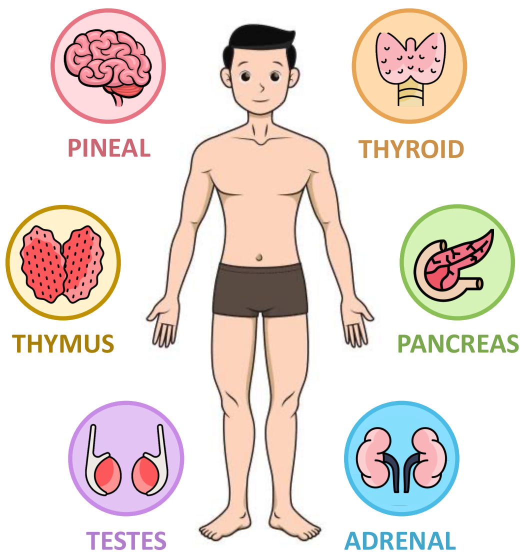
ENDOCRINE GLANDS

Endocrine glands secrete their product (hormones) directly into the bloodstream, rather than through a duct (exocrine glands).

Endocrine glands involved in homeostatic regulation include:

- Pancreas – makes insulin and glucagon (control blood sugar)
- Thyroid gland – produces thyroxin (regulates metabolism)
- Adrenal gland – secretes adrenaline ('fight or flight' actions)
- Pineal gland – releases melatonin (sets circadian rhythms)
- Ovaries – synthesises female sex hormones (e.g. estrogen)
- Testes – makes the male sex hormone (e.g. testosterone)

The hypothalamus and the pituitary gland are neuroendocrine glands and function to link the nervous and endocrine systems, as both systems are necessary to maintain internal equilibrium.



Examples of human endocrine glands